Satellite Cal/Val

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Introduction

- ESRL uses satellite data and products in almost every aspect of its mission.
- Within the ESRL Global Systems Division, our recent focus has been on Cal/Val of satellite data and products assimilated into current and future generations of atmospheric models.
- This work is a collaborative effort between ESRL and researchers at NESDIS, the JI's at CIRA, CIRES & CIMSS, and the UCAR COSMIC Program.
- Our briefing today focuses on the utility of ground and space-based GPS/GNSS observations to help us in this area.

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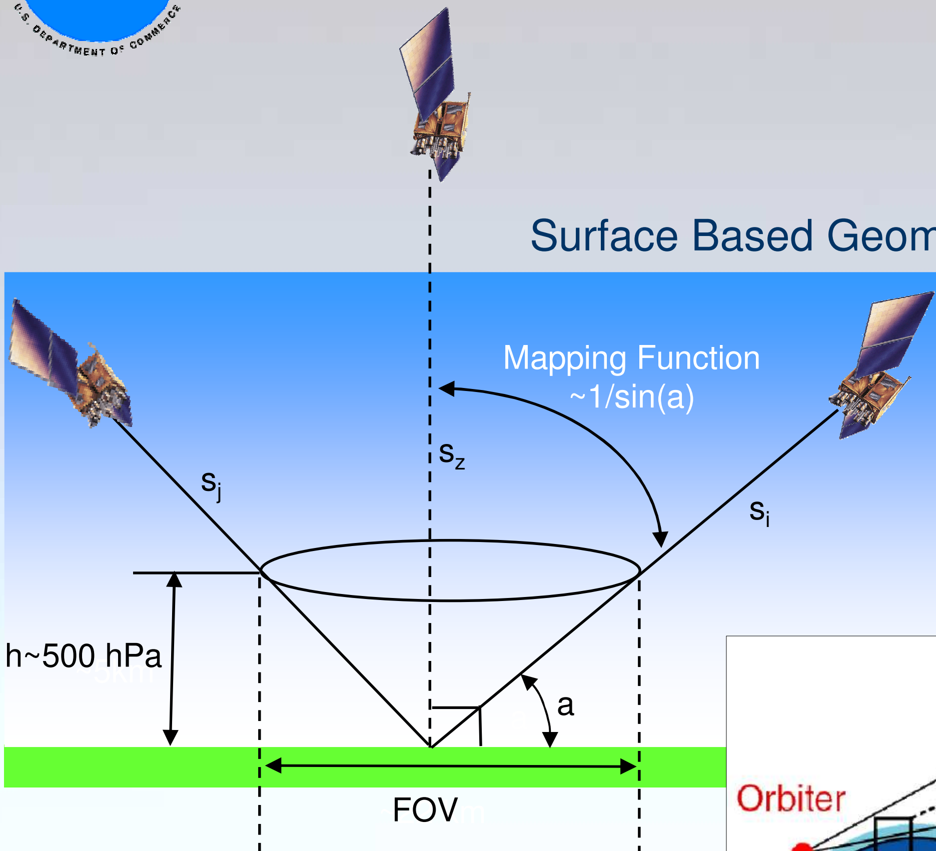
GNSS Observations in Meteorology

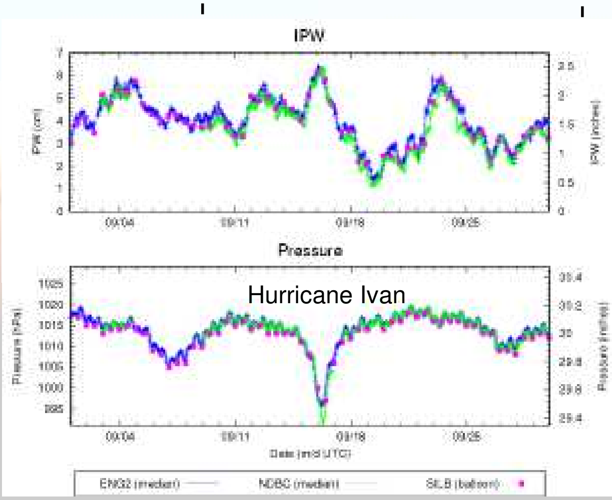
In both cases, the fundamental measurement is

$$\Delta s = 10^{-6} \int_s N(s)ds$$

N(s) = the refractivity of the atmosphere along the path of the radio signal $N(s) = 10^6 (n(s)-1)$.

Surface Based Geometry





Space Based Geometry

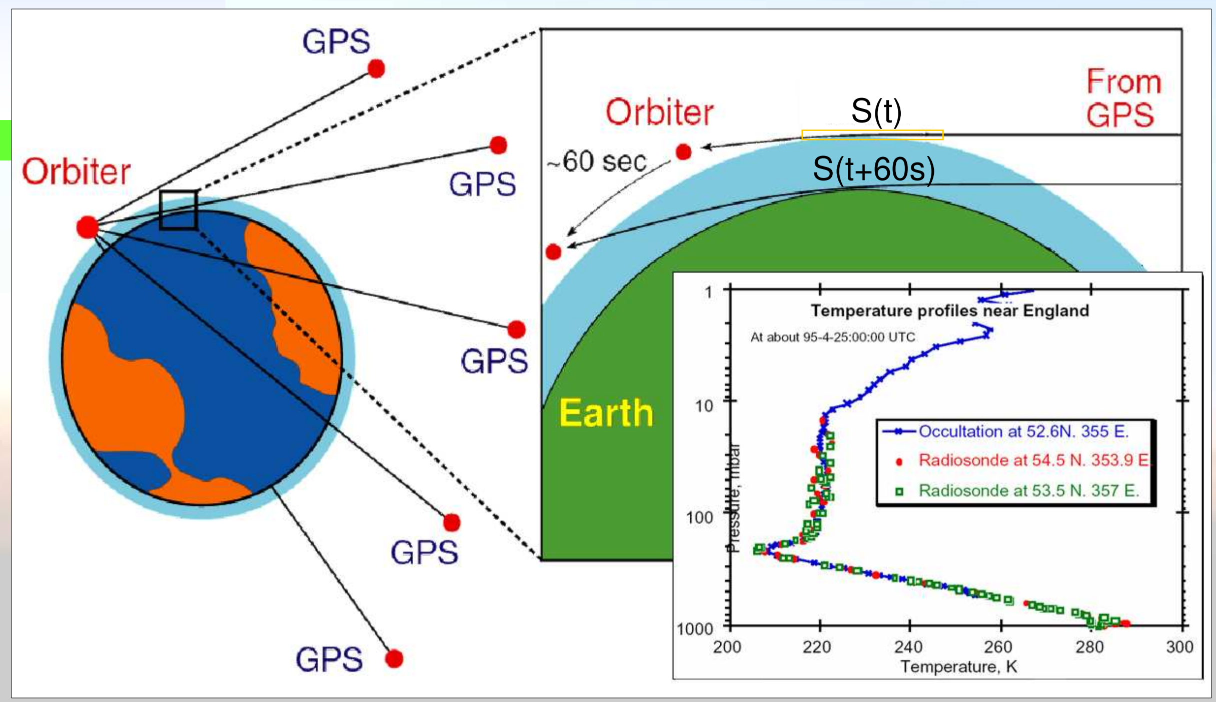
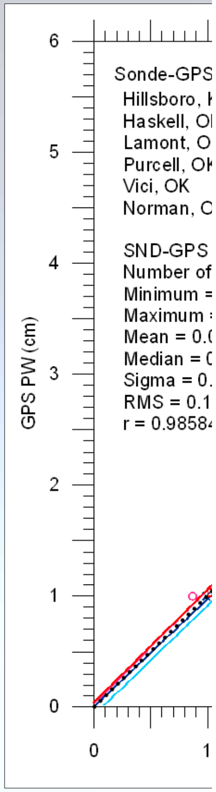
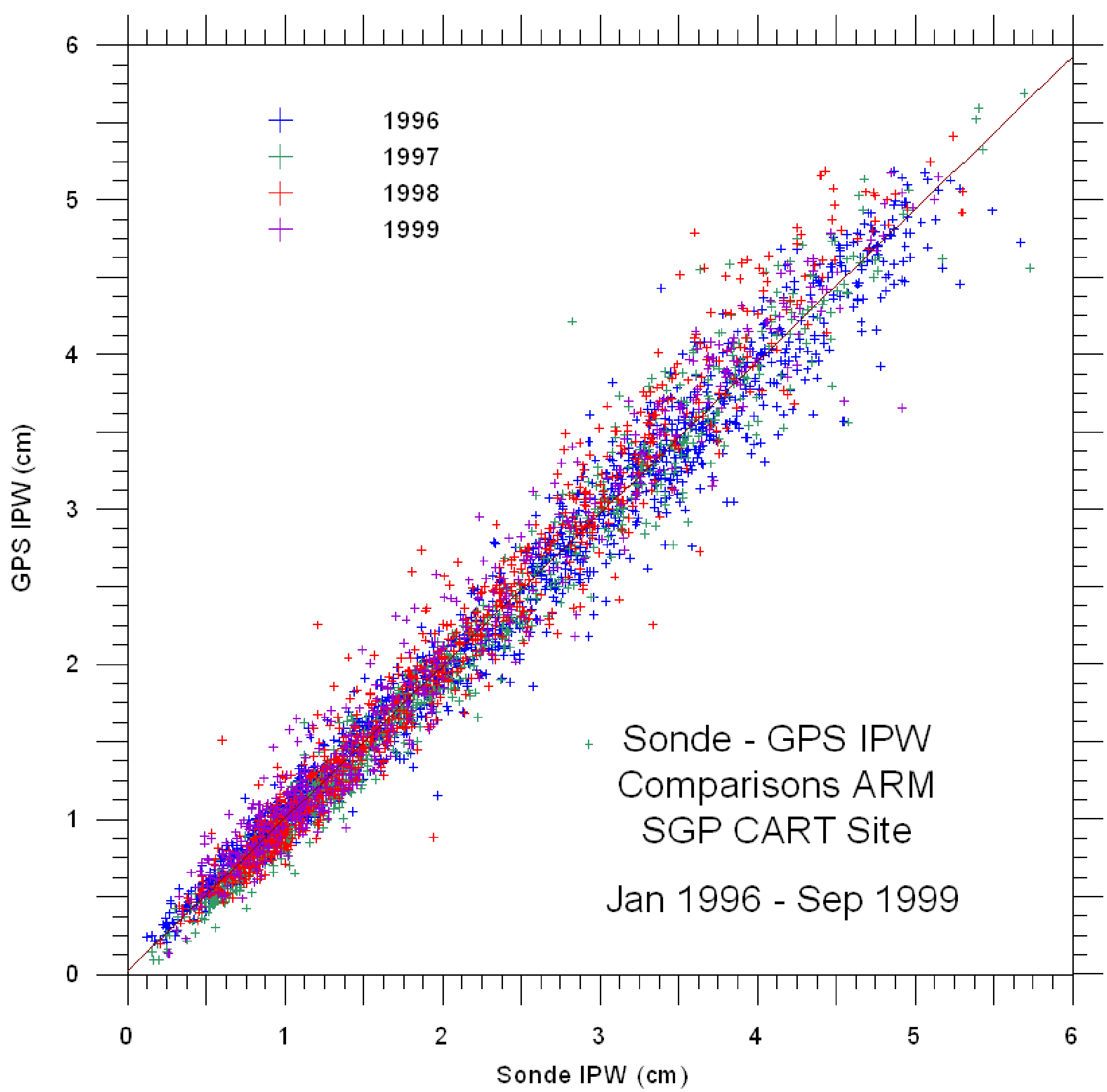


Illustration above courtesy of T. Yunk, NASA JPL.

GPS-Met Attributes





1996
N = 1382
Mean Dif. = 0.0346 cm
Std. Dev. = 0.1977 cm
Corr. = 0.9886

1997
N = 813
Mean Dif. = 0.0501 cm
Std. Dev. = 0.1965 cm
Corr. = 0.9874

1998
N = 771
Mean Dif. = -0.0431 cm
Std. Dev. = 0.2308 cm
Corr. = 0.9817

1999
N = 551
Mean Dif. = -0.0460 cm
Std. Dev. = 0.2070 cm
Corr. = 0.9851

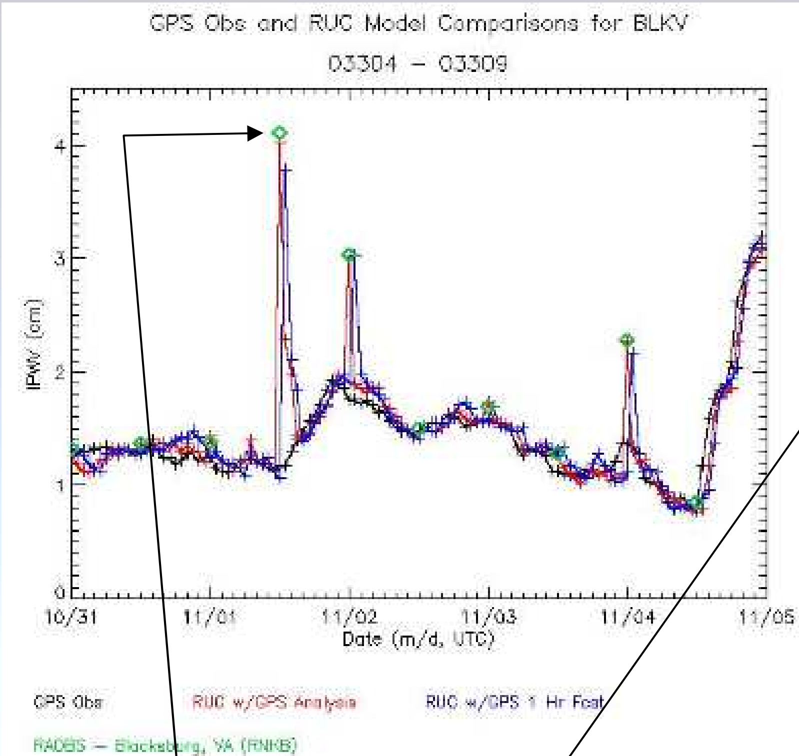
1996 - 1999
N = 3600
Mean Dif. = 0.0080 cm
Std. Dev. = 0.2102 cm
Corr. = 0.9854

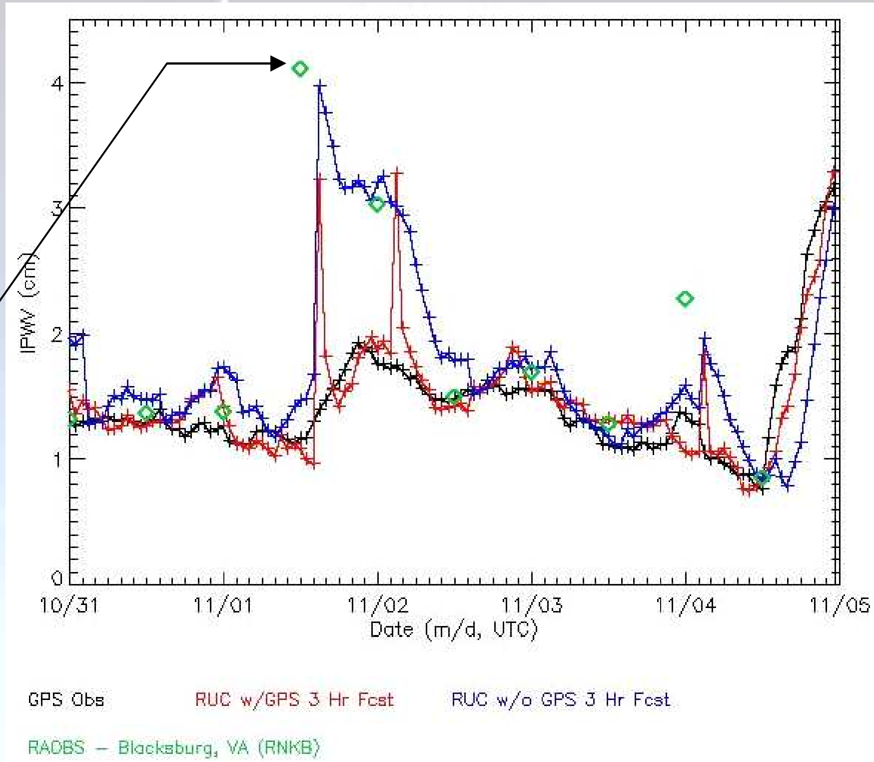
Equation of best fit line
Y = 0.9876125443 * X + 0.01837114798

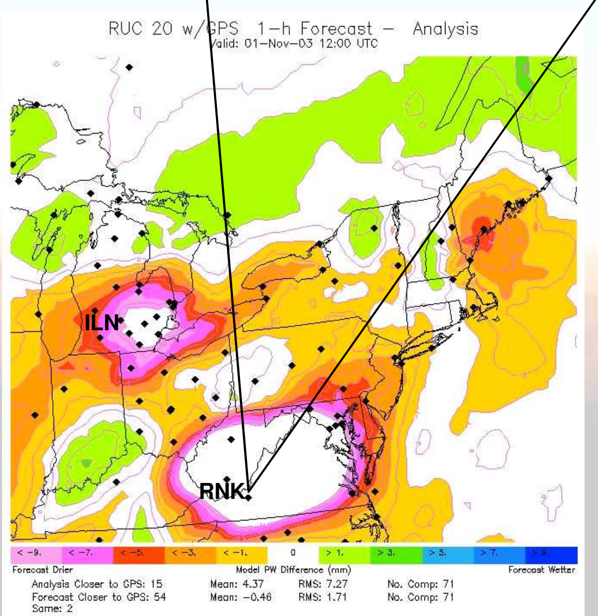
Background

- Our division has led NOAA’s development and testing of ground-based GPS techniques for atmospheric remote sensing.
- GPS Met is scheduled to transition from NOAA Research to NWS Operations starting in 2010.
- All-weather IPW data are currently retrieved from GPS carrier phase observations made at about 400 sites in CONUS and O-CONUS.
- These measurements are available to forecasters, modelers and researchers every 30 min, and the data are currently used in several NESDIS products.
- GPS-Met is also used by NWS for radiosonde QC and it will be incorporated into the baseline configuration of all global GRUAN sites.

GPS-Met/Radiosondes





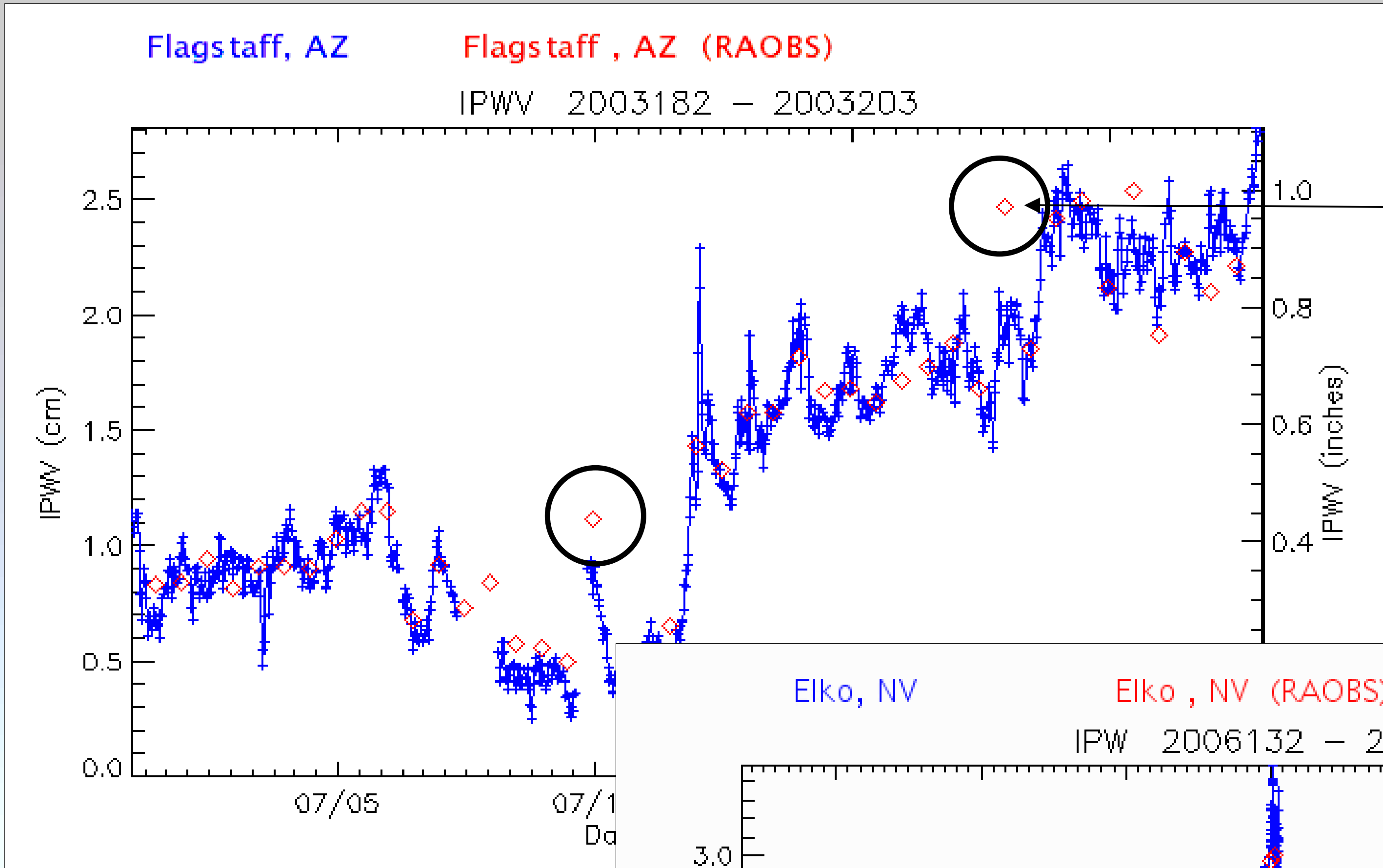


Impact of a RAOB moisture errors on weather forecasts.

Upper left: version of RUC assimilating GPS

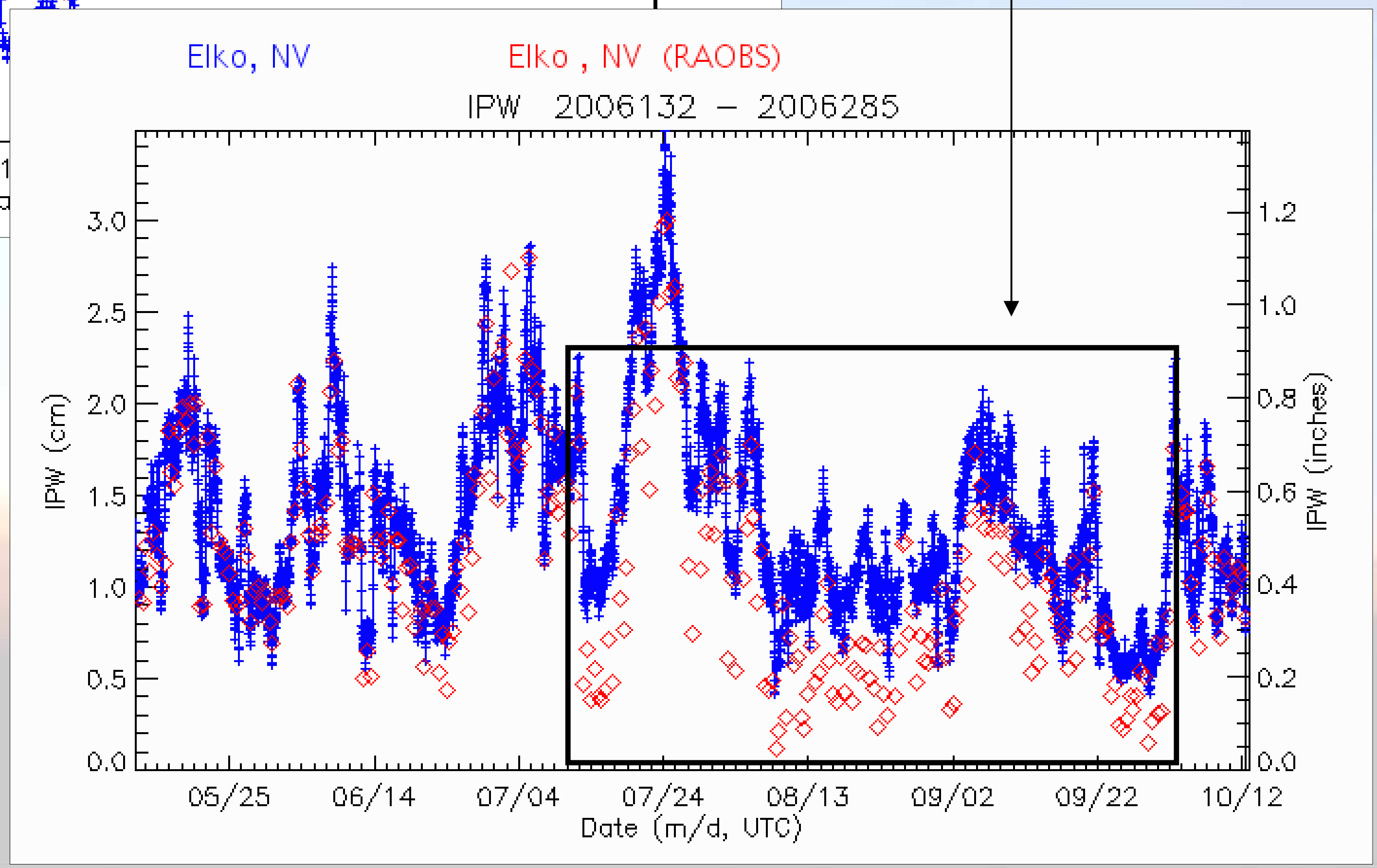
Upper right: version of RUC not assimilating GPS

Using GPS to identify RAOB moisture sounding problems



Non-Systematic Problems

Systematic Problems



Key Points

- After more than 60 years, radiosondes are still the backbone of the global upper-air observing system.
- They serve as “ground-truth” for satellite-derived estimates of temperature, moisture and other parameters.
- As a consequence, the accuracy of weather warnings & forecasts, global climate monitoring, and predictions depend on the accuracy of a few critical upper-air observations.
- Raobs can be difficult to verify because (1) they are launched infrequently from widely spaced locations and (2) other observations are rarely available for comparison.

Key Points

- Validation of satellite retrievals can also be difficult precisely because of the lack of independent observations, especially in remote locations.
- As technology advances, and new ways of making measurements are developed or made more economical, it becomes feasible to make comparative measurements of the same parameters using totally independent techniques.
- One such technique is Ground-Based GPS Meteorology (GPS-Met).
- We have become strong proponents of using ground and space-based GPS Met to Cal/Val global satellite obs and QC radiosondes.

GPS Contributions to Satellite Cal/Val

- This conclusion is based on the work we did on 2 and 3-way comparisons between AIRS, radiosonde and GPS water vapor measurements that were conducted over a 17 month period between April, 2003 and October, 2004*.
- AIRS, radiosonde and GPS data were screened to eliminate clearly erroneous measurements.
- Temporal and spatial matches (within 1-h & 50 km) were used to determine bias and variance between each observing system.

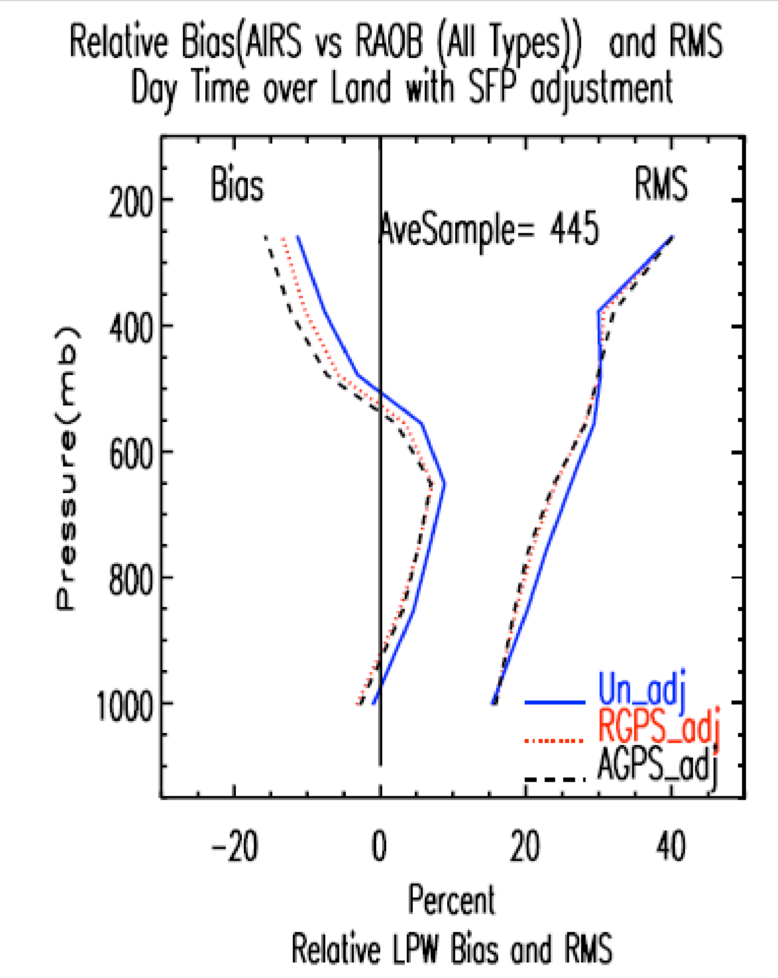
*McMillin, L. M., J. Zhao, M. K. Rama Varma Raja, S. I. Gutman, and J. G. Yoe, 2007. Radiosonde humidity corrections and potential Atmospheric Infrared Sounder moisture accuracy, J. Geophys. Res., 112, D13S90, doi:10.1029/2005JD006109.

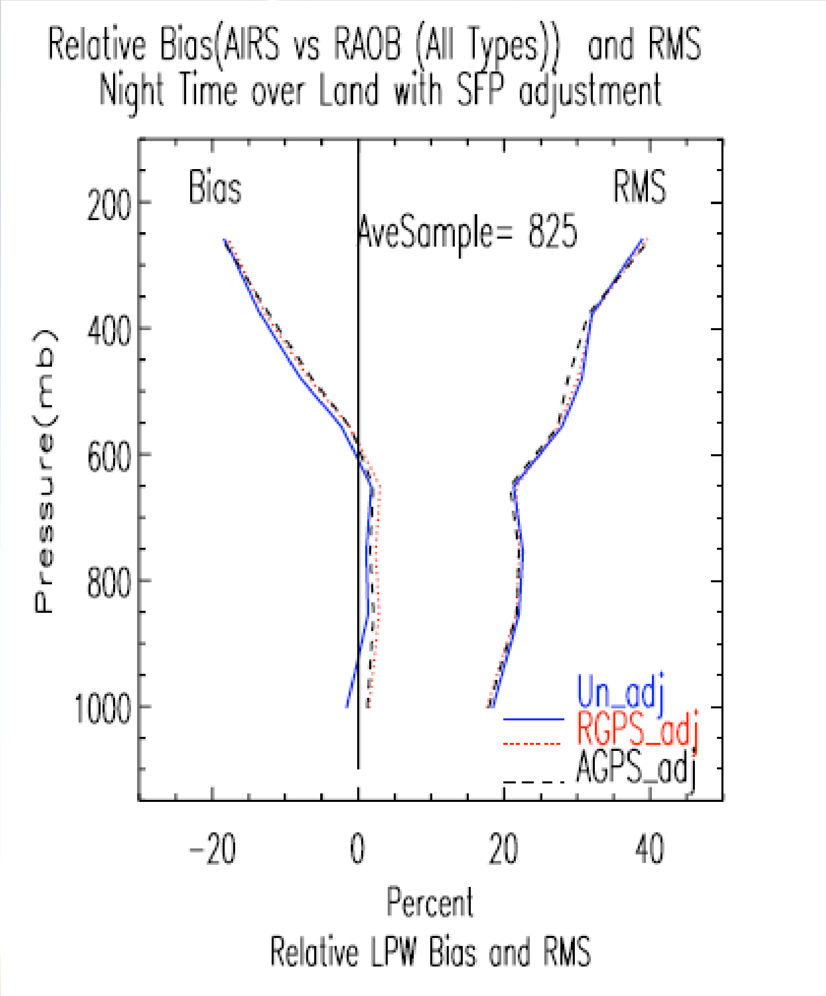
*Rama Varma Raja, M.K., S.I. Gutman, L.M. McMillin, J.G. Yoe, and J. Zhao, 2008. The Validation of AIRS Retrievals of Integrated Precipitable Water Vapor Using Measurements from a Network of Ground-Based GPS Receivers over the Contiguous United States, J. Atmos. Oceanic Technol., 25, 416–428.

Procedure

- Radiances calculated from unadjusted radiosonde moisture soundings were compared with observed AIRS radiances.
- Systematic errors were noted. Our hypothesis was that the errors were coming primarily from the radiosonde (RS80-57H) moisture sensor.
- Each radiosonde moisture sounding was adjusted to minimize the difference between the GPS IPW and the radiosonde PW measurement (Turner et al. 2003, Revercomb et al. 2003, Ferrare et al. 2004).
- Here are the published results.

Differences Between AIRS and RAOB Soundings*





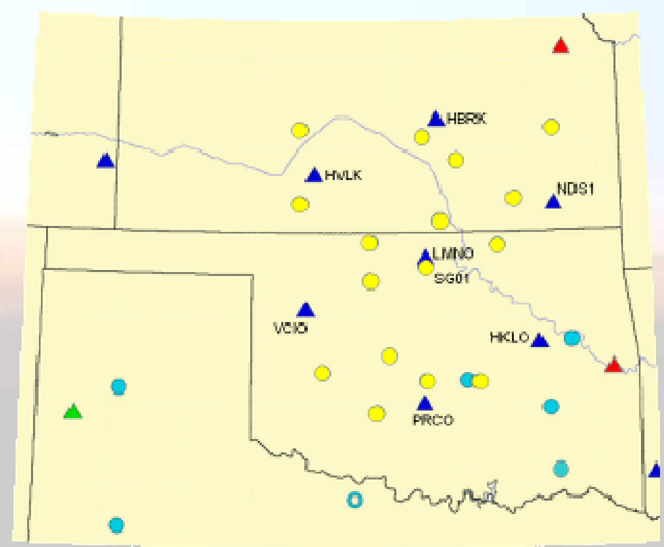
Daytime

Nighttime

* With and without GPS bias correction applied to radiosonde moisture sounding

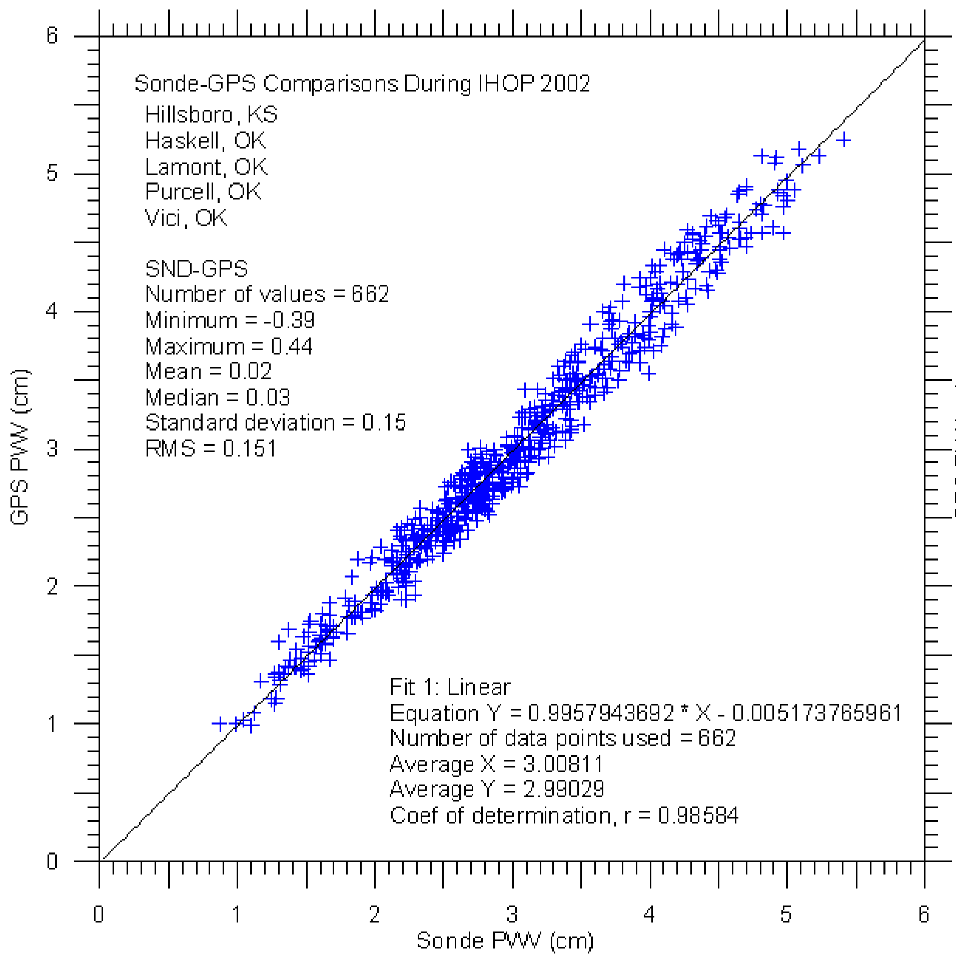
IHOP 2002 - Application to GOES Sounder Data

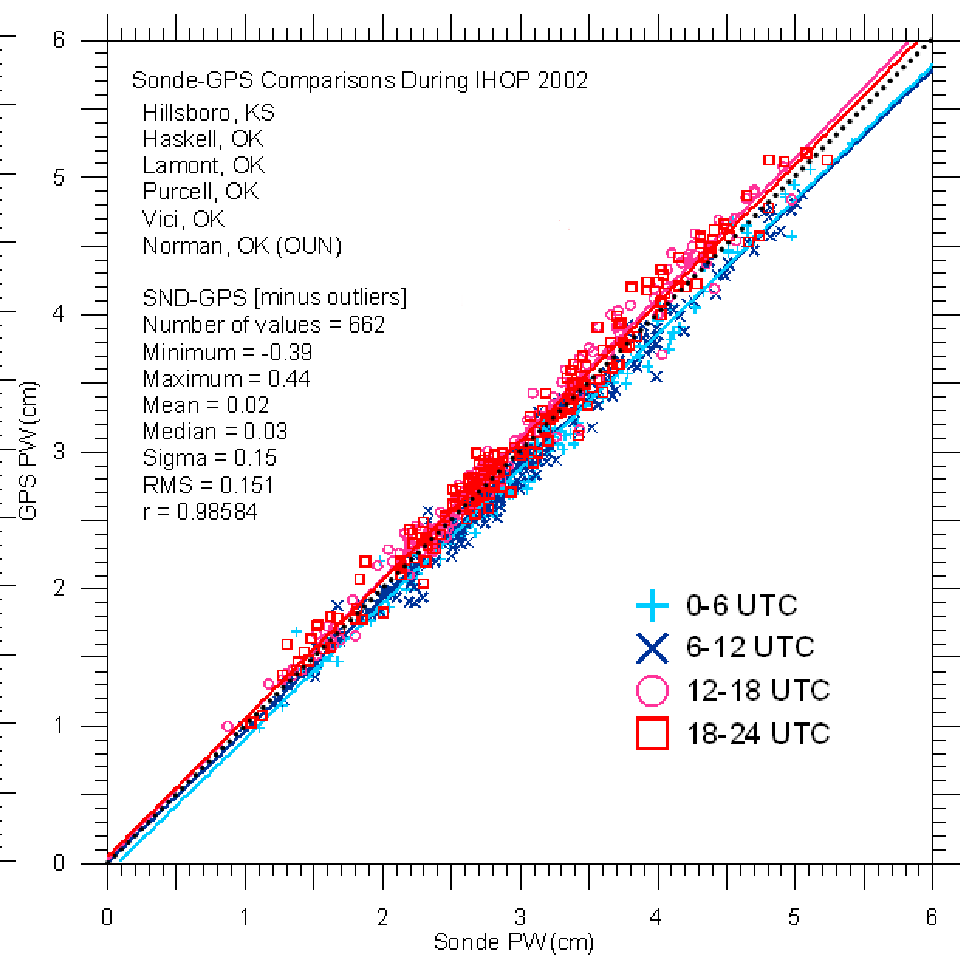
- Starting in 2005, we also compared PW from the GOES-8 sounder with ARM radiosonde and GPS IPW acquired during IHOP 2002 experiment between 26 May and 15 June.
- ARM sondes were launched at 3-h intervals from 5 sites, and GPS PW were available continuously at all sites.
- This gave us an opportunity to perform 24/7 3-way comparisons between GOES, radiosondes, and GPS.
- The results were surprising.



Diurnal Variability

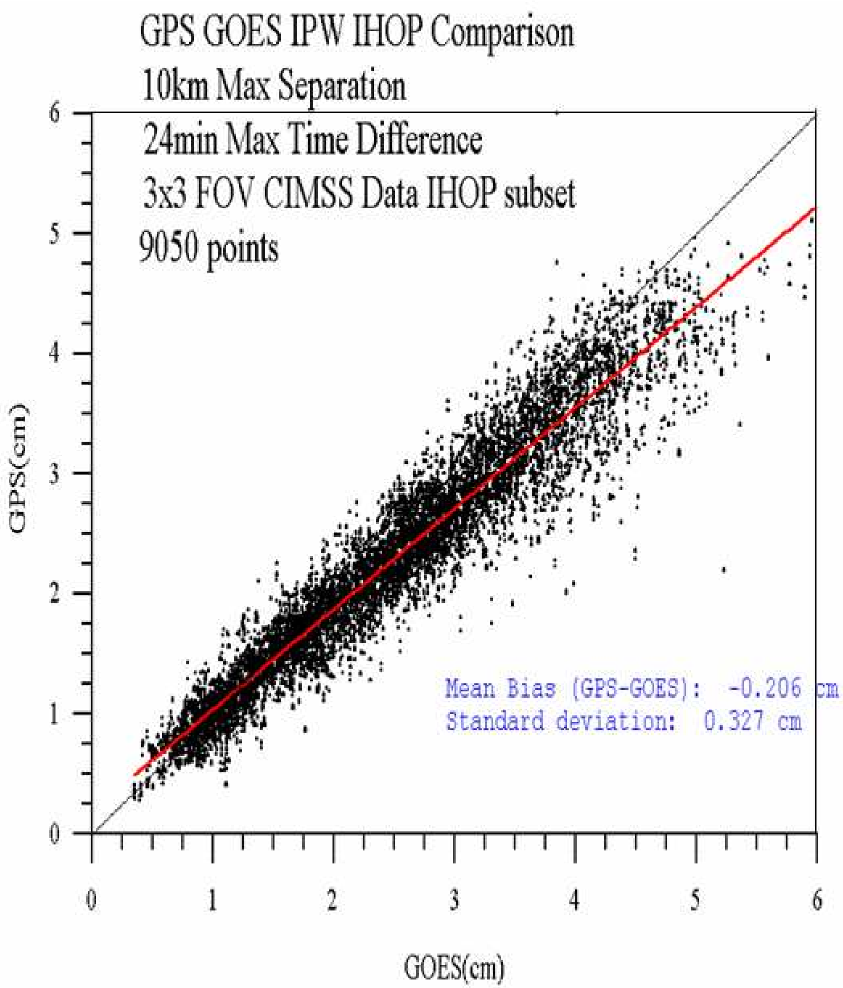
Comparisons during IHOP 2002 Experiment

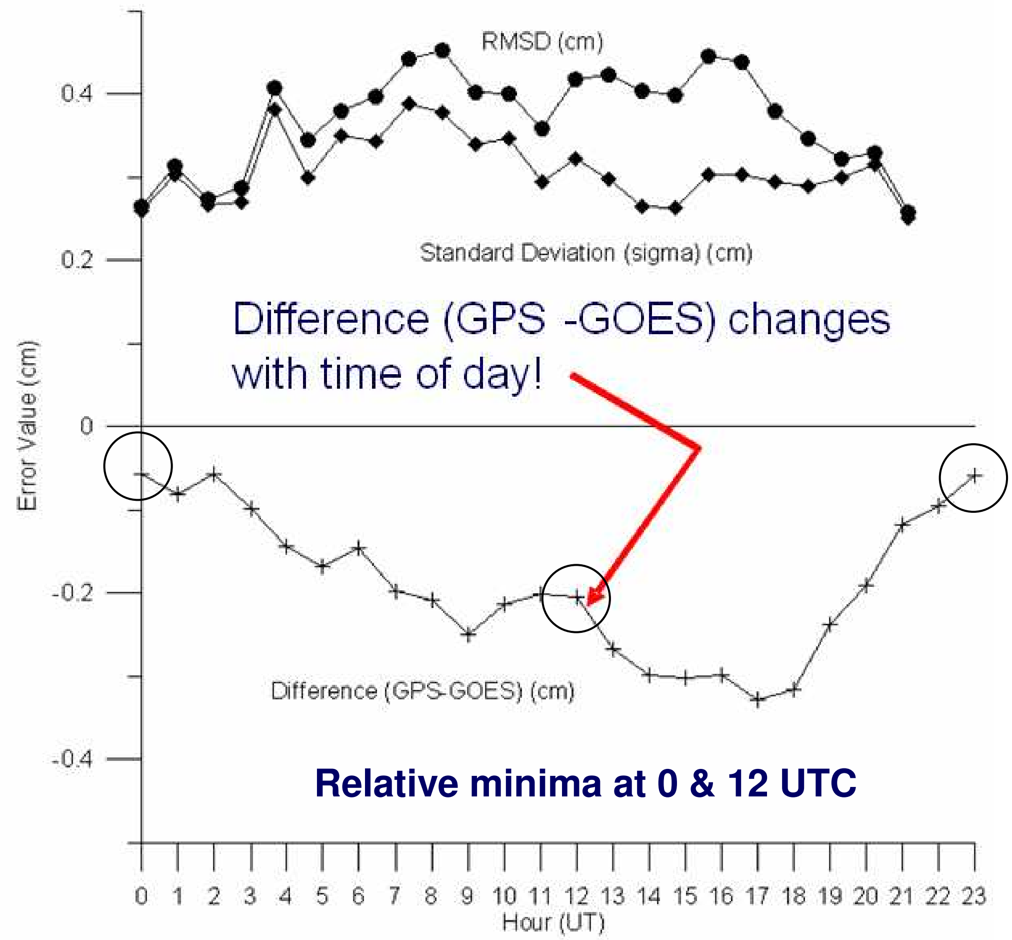




* This is observed “oscillation” is physically consistent with the results from McMillin et al 2007!

GOES 8 – GPS TPW Comparisons During IHOP 2002





REF: Birkenheuer, D., and S. Gutman, 2005. A comparison of the GOES moisture-derived product and GPS-IPW during IHOP. J. Atmos. Oceanic Tech. 22, 1838-1845.

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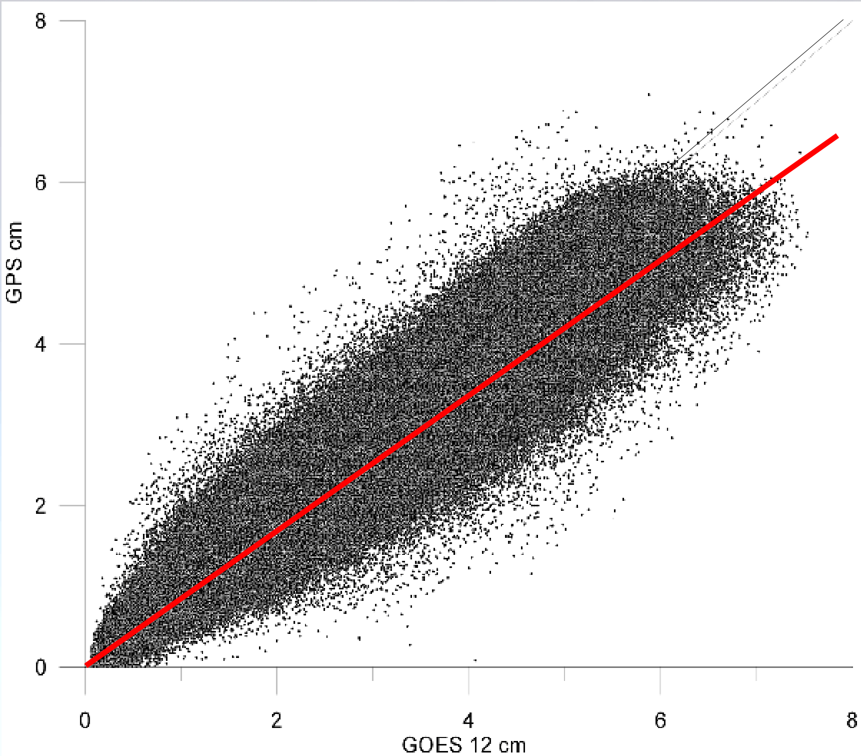
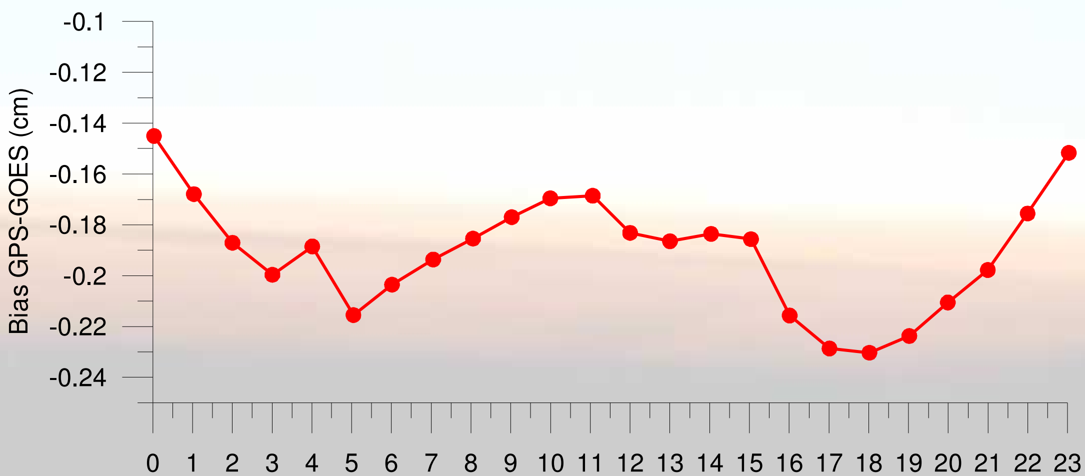
Repeated the Experiment 2 Yrs Later





Top:
GOES vs GPS

June 2005 - Jan 2007

num = 1,846,382

mean dif = 0.19 cm

sigma = 0.34 cm

Bottom:
GOES - GPS
as a function of time of day

June 2005 to January 2007

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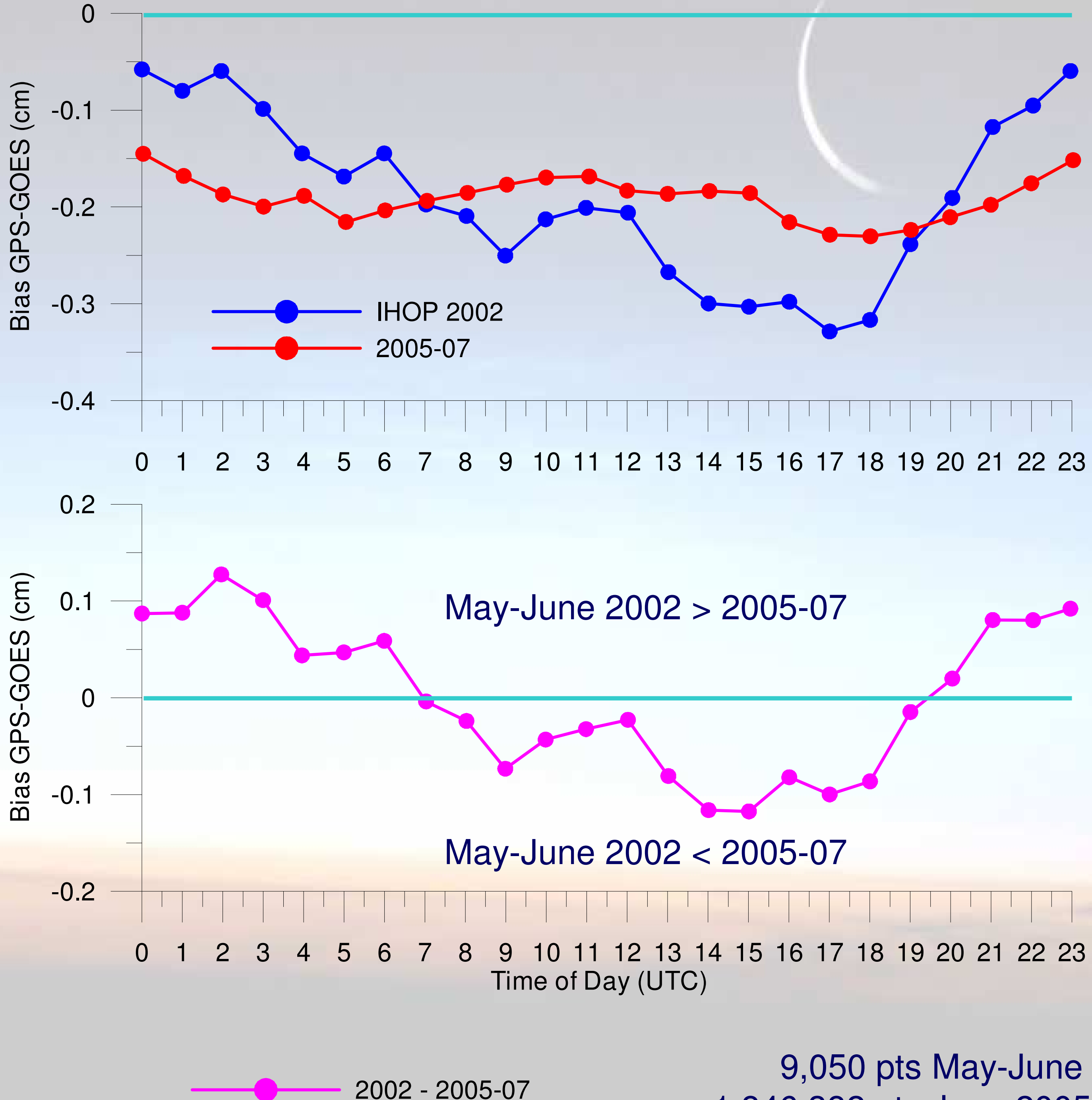
Differences



9,050 pts May-June 2002
1,846,382 pts June 2005-Jan 2007

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Empirical Correction Scheme

- We weren't sure of the cause, but the results were similar to 2002.
- We hypothesized that even if we couldn't correct for the variance we could at least estimate and minimize the systematic (diurnal) error.
- We assumed that a bias correction would follow a simple power law relationship of the form:

$$G_c = aG^b \qquad (1)$$

where G_c is the corrected GOES moisture value, G is the value provided to us by NESDIS, $\boldsymbol{a}$ is the scaling term and $\boldsymbol{b}$ is a power term. Both $\boldsymbol{a}$ and $\boldsymbol{b}$ are dimensionless.

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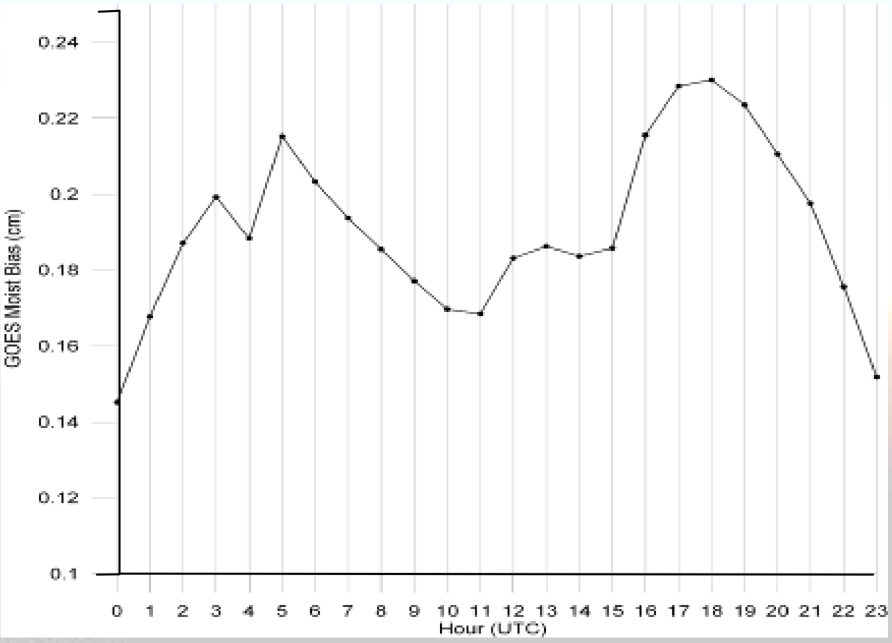
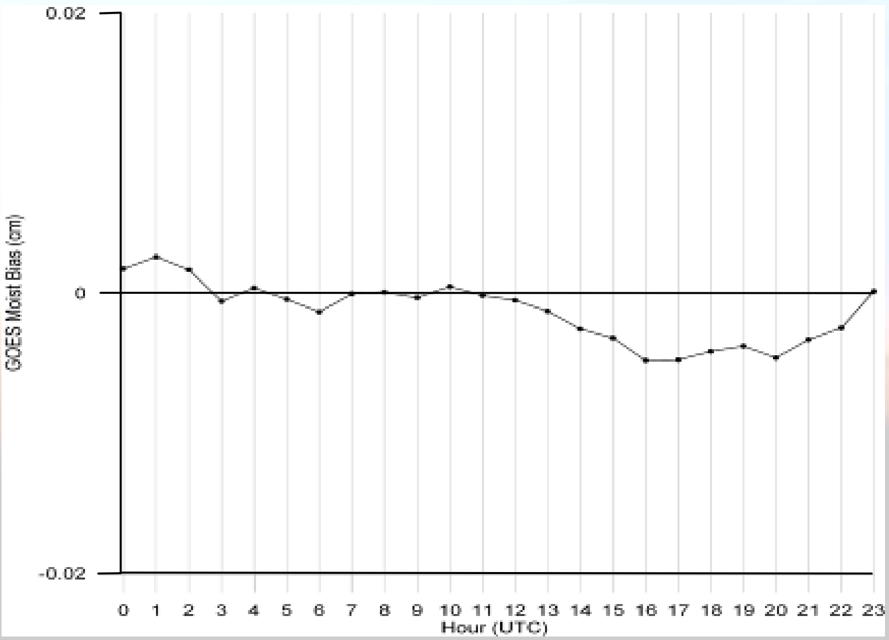
Empirical Correction Scheme

We took a variational approach to solve Equation 1 where $\boldsymbol{J}$ is a functional is defined by:

$$J = \sum_{i=1}^{N} (G_{ci} - GPS_i)^2 \qquad (2)$$

Our goal is to minimize $\boldsymbol{J}$ by modifying coefficients $\boldsymbol{a}$ and $\boldsymbol{b}$ in Equation 1 using the method of Powell (1962), and summing over all data points $i = 1,N$.





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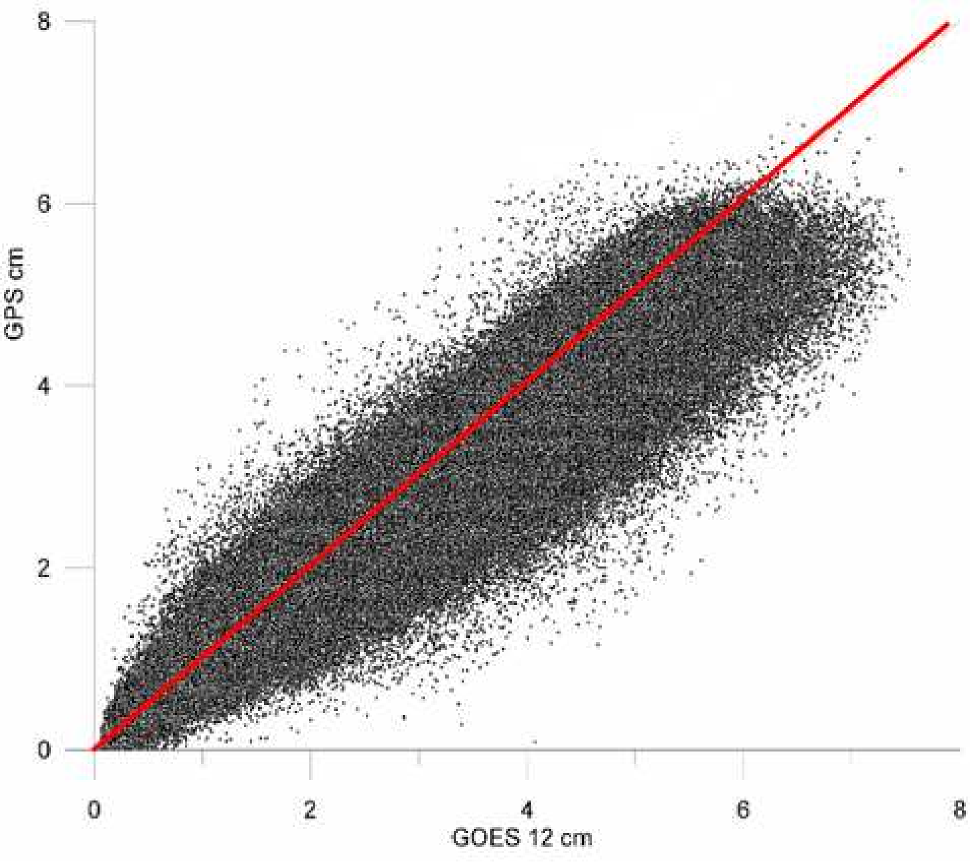
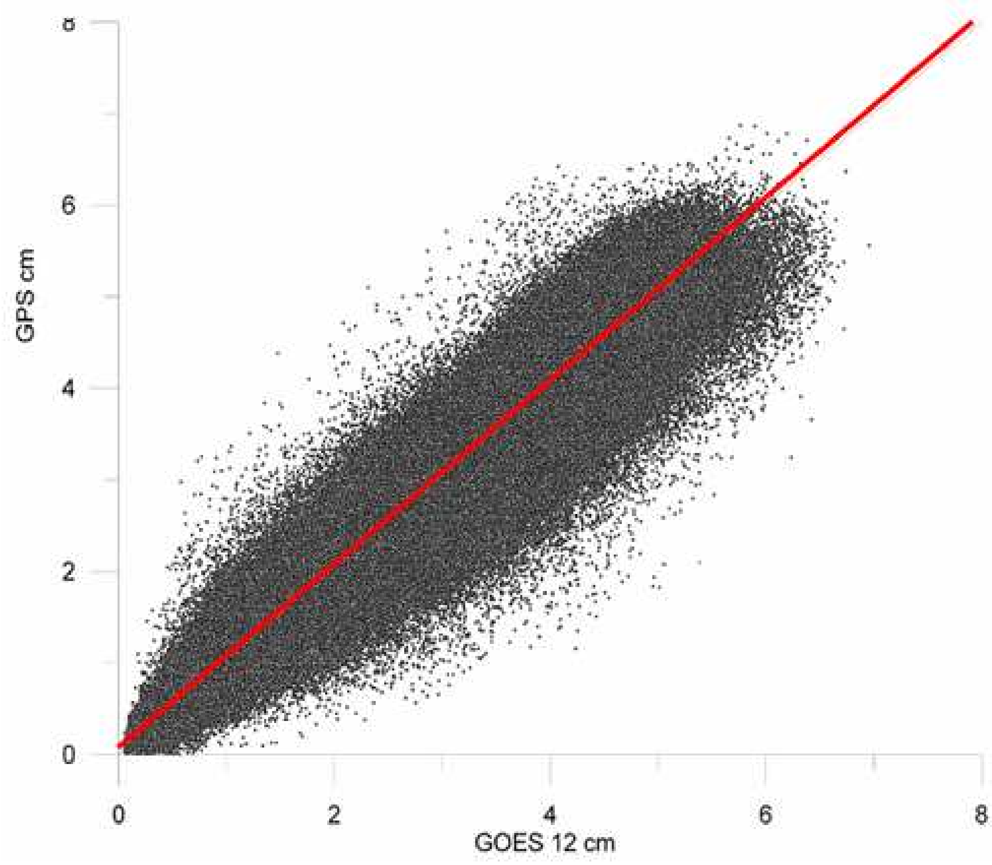
Bias Corrected GOES 12 Data

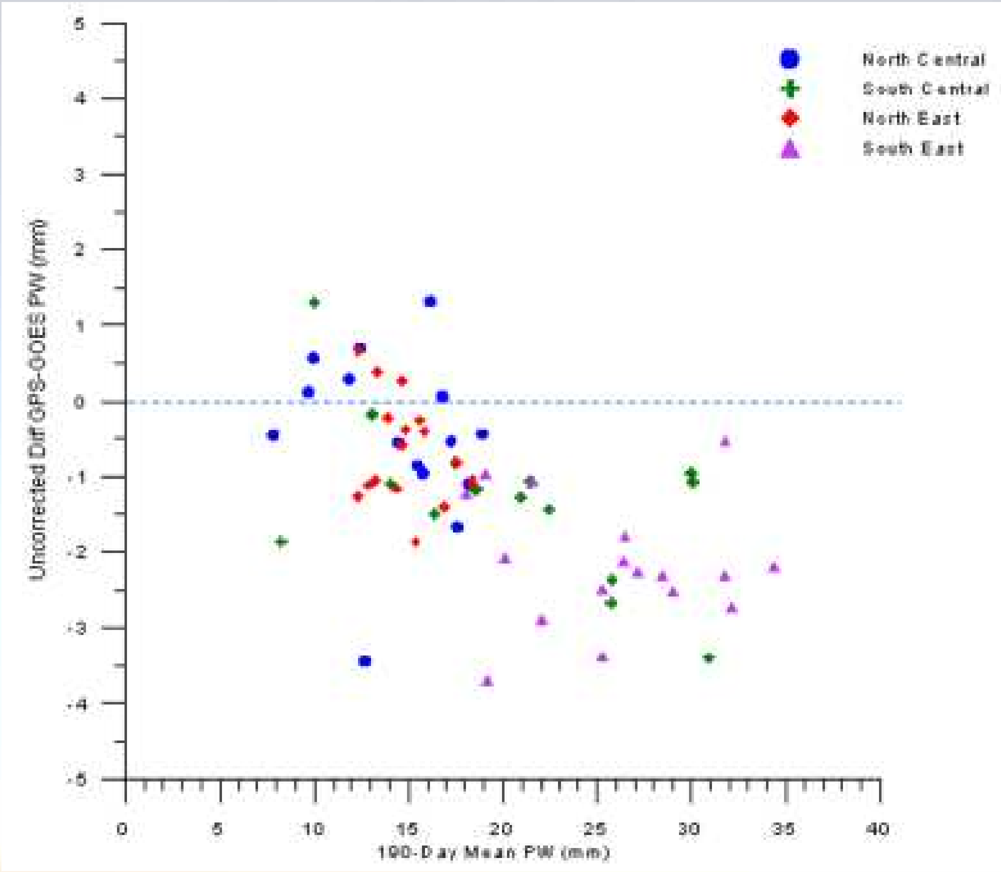


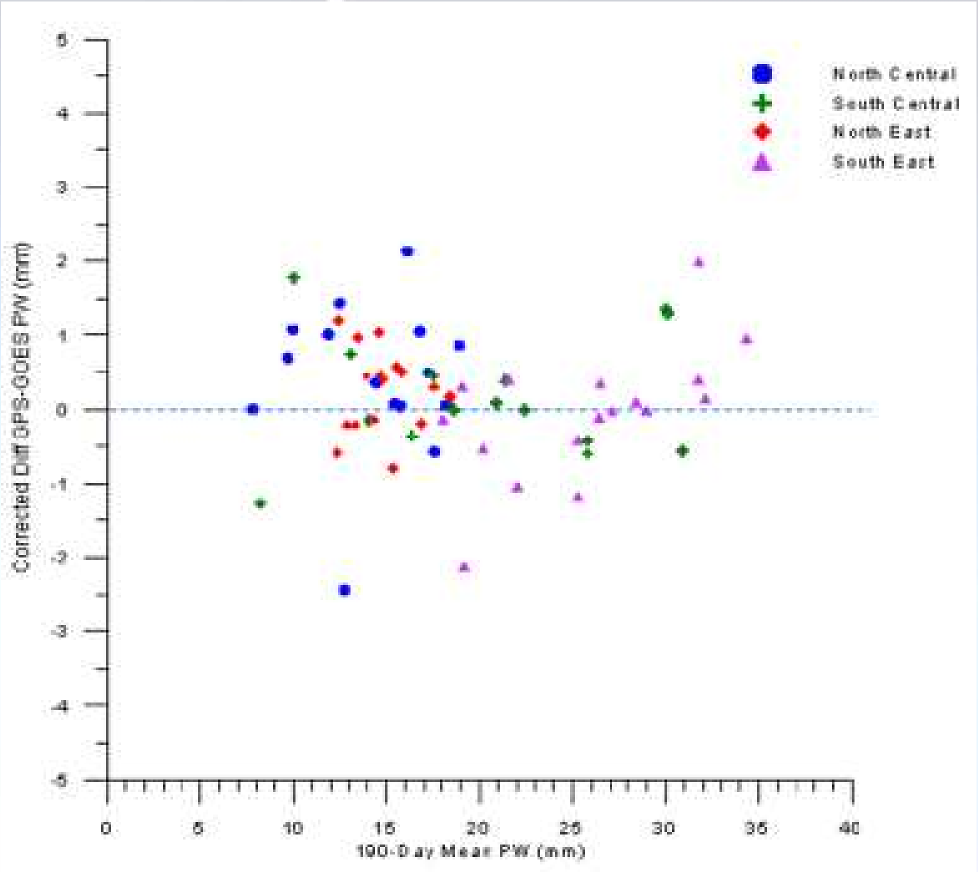
Before Correction



After Correction

CONUS Geographic Dependence

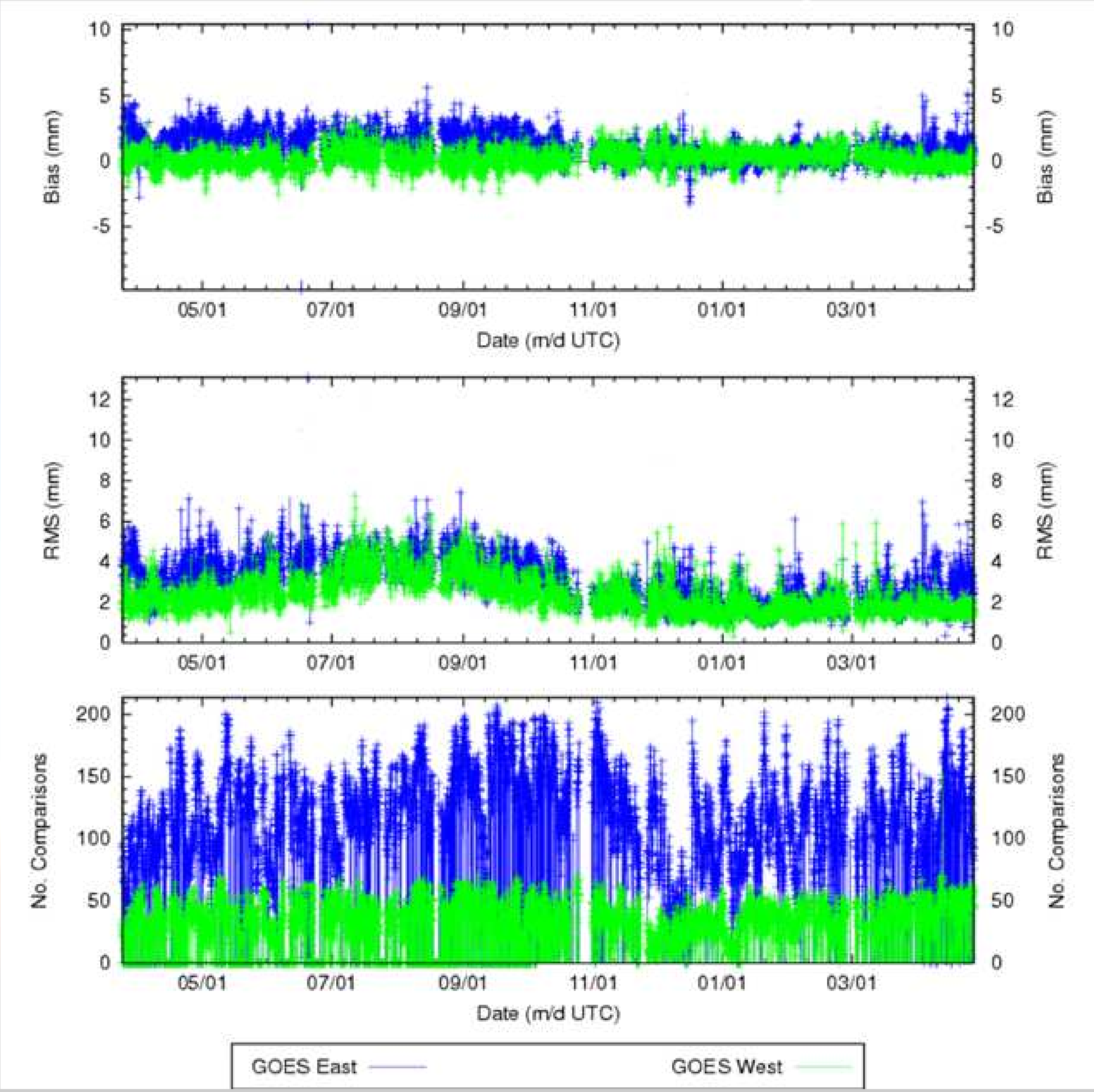




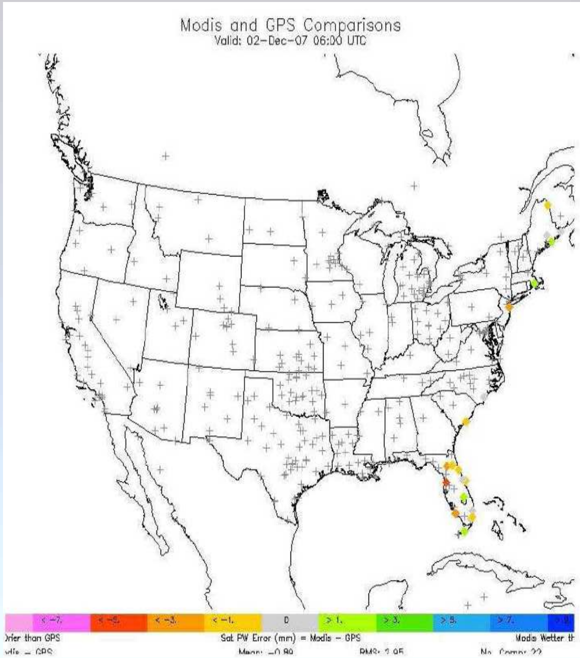
Before Correction

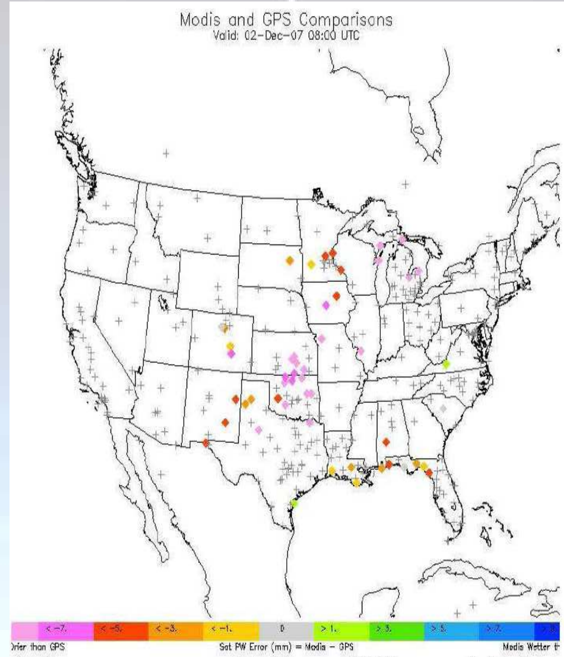
After Correction

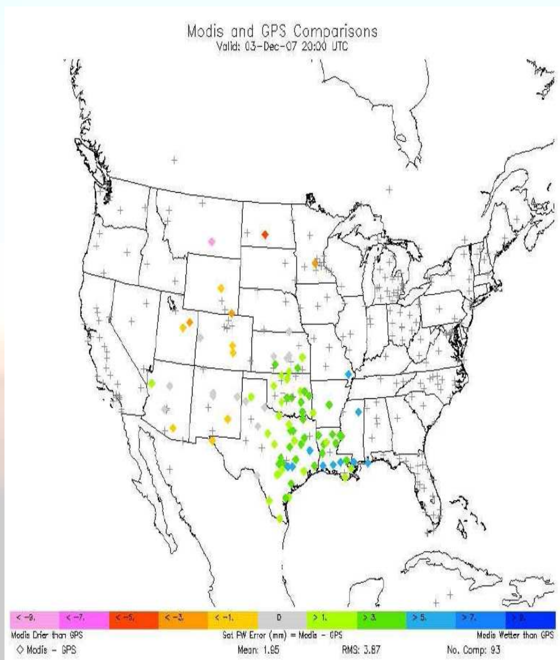
Differences Between GOES 12-10

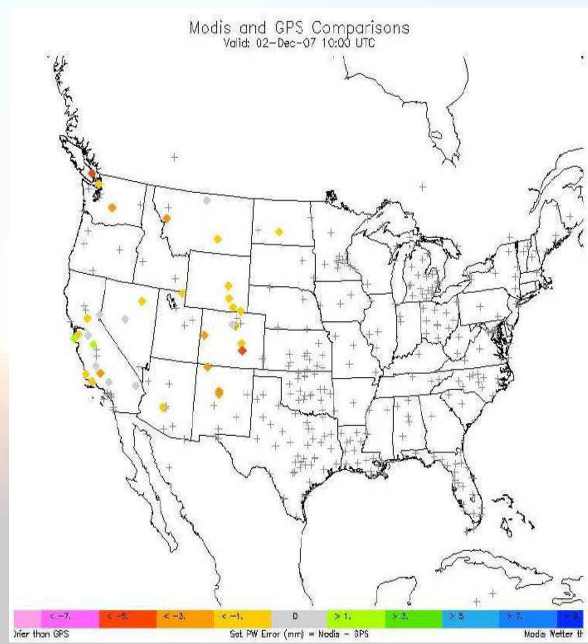


MODIS Proxy for GOES-R ABI

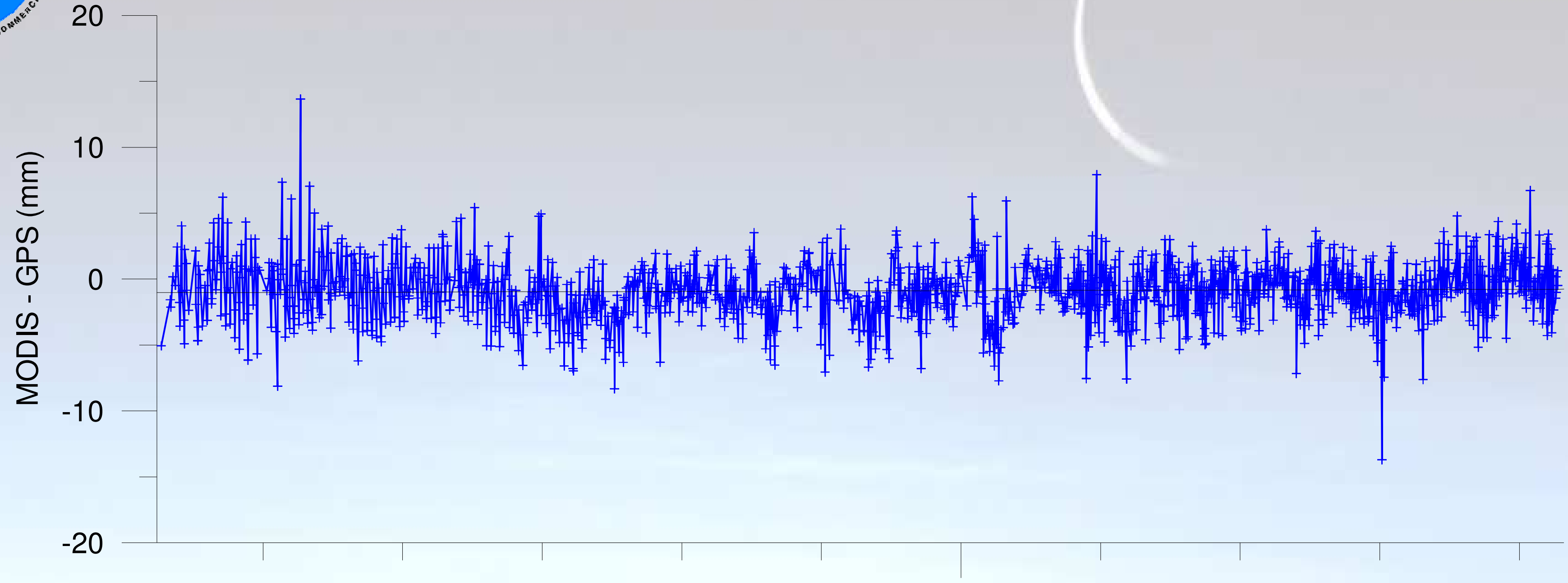


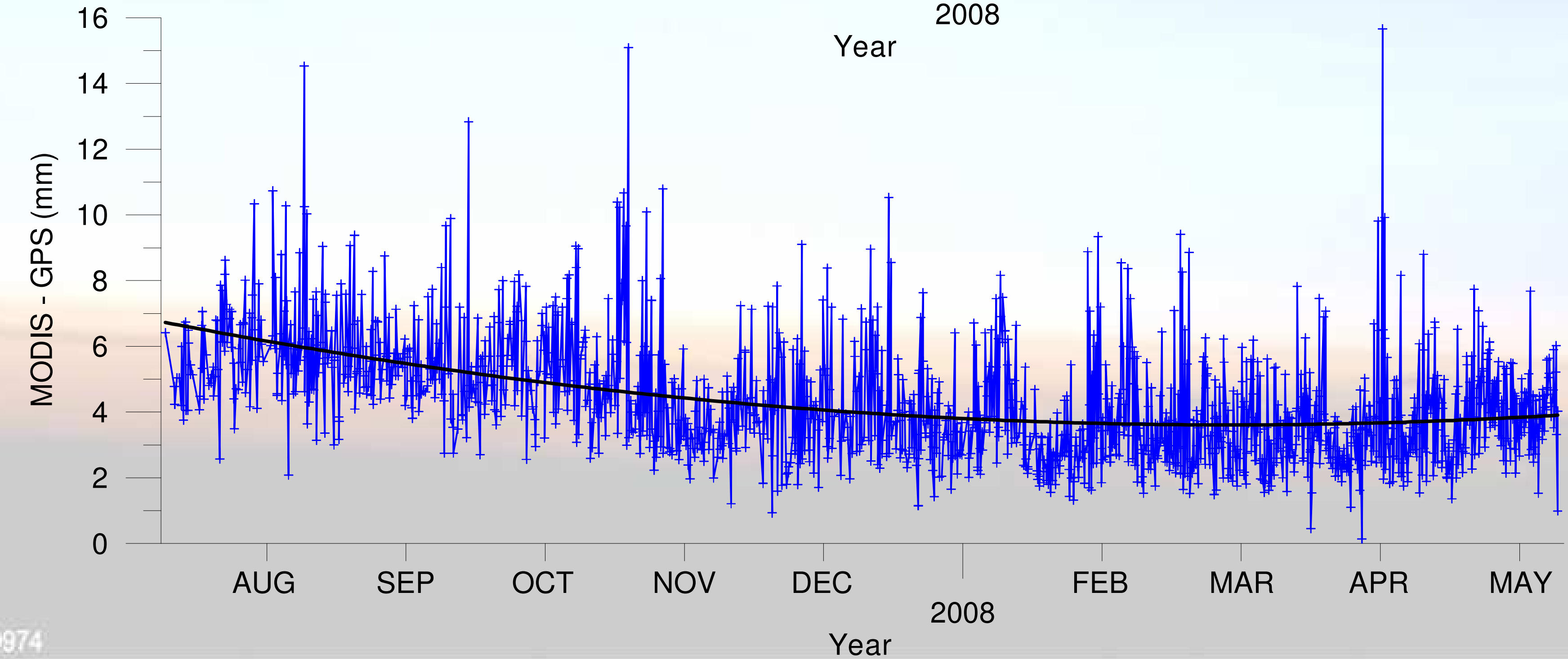






MODIS Proxy for GOES-R ABI





Conclusions

- All evidence indicates that the accuracy of ground and space-based GPS measurements of refractivity (or total signal delay) are temporally invariant.
- There are systematic differences observed between satellite (GOES, AIRS, MODIS) TPW estimates and GPS IPW retrievals.
- These occur over timeframes ranging from diurnal to seasonal.
- The differences are probably larger than the expected interannual-decadal changes due to climate change, and this exacerbates the problem of identifying climate change signals in satellite observations.

Conclusions

- The high temporal resolution and all weather operability of GPS allows us to implement continuous quality control of radiosondes, and Cal/Val of satellite (GOES-R & NPOESS) soundings for the first time.
- The total life cycle cost of GPS-Met is so low that we can afford to deploy them almost anywhere on the planet.
- Although not discussed in this presentation, GPS-RO also has significant potential for satellite Cal/Val, especially for intercalibrating radiometers.

Recommendations

- Install ground-based GPS/GNSS receivers at all GUAN and all future GRUAN sites.
- Incorporate GPS/GNSS R&D in all satellite data exploitation activities.
- Install GPS Met sensors on offshore platforms so we can verify the accuracy and stability of passive microwave observations over the oceans.
- Exploit the nearly decade-long record of GPS/GNSS observations for climate studies, especially at the Poles.
- Produce retrospective and ongoing climate products from GPS-RO and GPS-Met observations to facilitate climate research and decision making.